A Proposal For:

# Warm Water Species Fish Passage in Eastern Montana Culverts

Submitted by:

Dr. Joel Cahoon, P.E., Ph.D.
Civil Engineering Department

Dr. Thomas McMahon, Ph.D.
Fish and Wildlife Program
Ecology Department

Otto Stein, Ph.D.
Civil Engineering Department

Jarrett Barber, Ph.D.
Statistics

Montana State University
Bozeman, MT 59715

Submitted to

MONTANA DEPARTMENT OF TRANSPORTATION
RESEARCH MANAGEMENT UNIT
2701 PROSPECT AVENUE
HELENA, MT 59620

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## Problem Statement

Culverts are a common and often the most cost effective means of providing transportation intersections with naturally occurring streams or rivers. Fish passage and fish habitat considerations are now typical components of the planning and design of waterway crossings. Many culverts in Montana span streams that support diverse fisheries. The health of these fisheries is an essential element of a recreational industry that draws hundreds of thousands of visitors to Montana annually. Additionally, there is growing recognition of the value of native Montana species, some of which are considered 'species of special concern' in the state. In recent years these concerns have become apparent for warm water species in low gradient, high sediment bearing, intermittently flowing streams that are typical of eastern Montana.

Transportation system planners, designers and managers recognize that fish passage through Montana's culverts is a concern. However, there is much contention concerning the impact that a culvert can have on a fishery. Recent basin-wide studies of various trout species that we conducted in western Montana indicate that the tools that some planners and designers promote for forecasting fish passage concerns may be overly conservative. Which species, life stages, and how many individuals must have fish passage access for how long, are questions that are often brought forward during discussions on the design and retrofitting of culverts to accommodate fish passage concerns. ***The problem is that for warm water fish species and settings in eastern Montana, the timing and number of fish that must pass a culvert to maintain viable species diversity in the watershed is unknown, and the physiologic abilities of these species relative to such common fish passage questions are often unknown.***

## Background Summary

Fish Passage Considerations

Regardless of species, the elements of a culvert that can present barriers to upstream fish migration are known, even if the extent to which these barriers prevent passage may not be. These common features of culverts that can inhibit fish passage are:

- Outlet drop - the approach to the culvert at the downstream end can have an outlet drop that may require fish to jump into the culvert. High outlet drops have a tendency to occur in high gradient streams.

- Water velocity/culvert length combinations - fish must be able to overcome the water velocity to make progress swimming upstream. Fish swimming is often described in three forms - sustained swimming, prolonged swimming, and burst swimming (Katopodis and Gervais, 1991). Sustained swimming is the speed that the fish can maintain for an indefinite period of time, prolonged swimming is a moderate speed that can be maintained for several minutes to a couple of hours and burst speed is the maximum speed that a fish can produce, usually maintainable for less than 15 seconds. To assess these factors in culverts, the culvert length is also considered to determine if the prolonged or burst speed is the appropriate comparison with the water velocity. High velocities can be overcome for short distances, while long pipes must have lower water velocity provided by low slope or velocity breaks that allow resting cover for fish during upstream passage through culverts.

- Insufficient water depth - the depth of flow in the culvert must be sufficient to accommodate fish mobility.

- Blocked inlet - excessive sediment or debris can deposit on the upstream end of the culvert (Kane and Wellen, 1985). This deposition often results when culverts constrict flow because their cross-sectional area is much less than that of the channel. Sediment buildup at the culvert inlet can lead to a steep inlet slope and high water velocity.

- Habitat alteration - there is anecdotal evidence that some fish species are hesitant to pass through culvert barrels where the vegetation, lighting and substrate composition is different from that in the stream.

Passage Prediction Tools

The dynamics of changing flow is one of the more complex factors involved in assessing, and predicting passage success at culverts. The FishXing software (Six Rivers … 1999) is designed to aid in analyzing fish passage through culverts. It uses 1-D gradually varied flow hydraulics to estimate water depths and velocities through a structure, and compares these to the swimming abilities of the fish of concern. Passage success is estimated based on this comparison.

**Objectives**

***The primary objective of this study is to determine the rate and timing of fish passage in culverts that is desirable for warm water species diversity maintenance in eastern Montana.*** Secondary goals are to discover fish passage issues for these species that may not be predicable from hydraulic analysis and to refine information about the physiologic abilities of these species to pass through culverts.

**Benefits**

The benefits of the project are:

1) There are many unknowns with respect to fish passage for warm water species in the low gradient and sediment bearing streams typical to eastern Montana. Overly conservative contemporary tools for estimating fish passage in culverts, coupled with unknowns concerning the significance of culverts as fish passage barriers to most warm water species in eastern Montana, can lead to the design of excessively costly installations, make it difficult to set priorities, and result in significant impacts to recreationally important and 'at-risk' fish species. The results of this project will allow designers and planners to arrive at more cost effective, but still fish-friendly, roadway water crossings.

2) The project results will help engineers and biologists understand the biological capabilities of fish relative to the hydraulic settings where warm water species are found.

## Research Plan

Study Sites

We are interested in sites where historic information is available, fish passage concerns have been previously expressed, and the site conditions lead to good experimental designs. Potential sites include main stems or tributaries of Beaver Creek in Wibaux county, the Poplar River in Daniels county, and the Musselshell River in Petroleum and Musselshell counties. Previous discussions with Fish, Wildlife, and Parks fishery biologists in the Miles City area have also voiced interest in fish passage issues in that area as well. All site-specific transportation related fish barriers could be included in the study if warranted. As in our previous work, we will consult widely with transportation planners and fishery biologists in the area to identify key fish passage issues and key sites where our study results would have the greatest impact on assessing and designing fish-friendly fish passage structures.

Timing of research activities will be critical. Some of the study areas are intermittent streams where fish migrate upstream during flashy spring flows and the spawning cycle is complete before these runoff flows subside and the creek dries up.

Fish Species

The results of a quick database survey of the present in the potential study watersheds are shown below as reported in internet-based data sheets provided by Montana Fish, Wildlife and Parks.

| **Fish Species** | **Beaver Creek**[a] | **Poplar River**[b] | **Musselshell Tributaries**[c] |
|---|---|---|---|
| Northern Pike | X | X | |
| Fathead Minnow | X | X | X |
| White Sucker | X | X | X |
| Shorthead Redhorse | X | X | |
| Green Sunfish | X | | X |
| Walleye | X | X | |
| Iowa Darter | X | | |
| Longnose Dace | | X | X |
| Pearl Dace[d] | | X | |
| Stonecat | | X | |
| Common Carp | | X | X |
| Spottail Shiner | | X | |
| Lake Chub | | | X |
| Mountain Sucker | | | X |
| Sand Shiner | | | X |

[a] River mile 84.3 to 84.4, September, 1999.
[b] River mile 93.7 to 93.8, August, 2000 and river mile 98.1 to 98.2, July 2000, July 2001 and September 2001.
[c] Box Elder Creek, river mile 8.7 to 8.8, August 2001, and Flatwillow Creek river mile 64.9 to 65.0, August 2001.
[d]Along with sauger, a *Fish of Special Concern* in Montana.

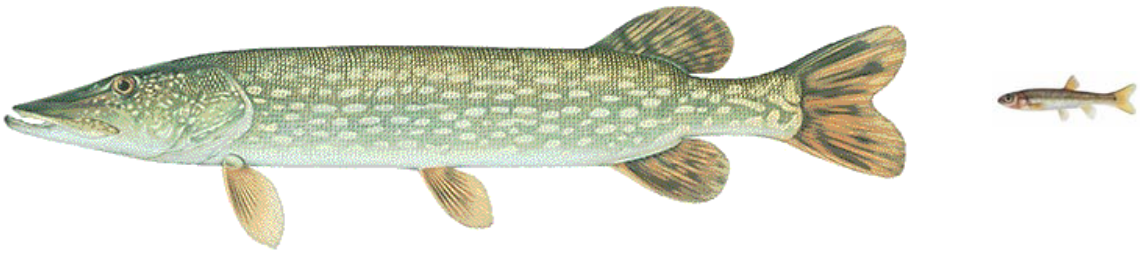


Figure 1. The fish species in this setting are very diverse. The state record northern pike (l) catch is 37.5 lb, while a large pearl dace (r) would be in the 6 inch range (drawings from Montana Fish, Wildlife and Parks).

Perusal of this list reveals several important points. First, that the fish species complement is much more diverse than smaller, higher gradient, coldwater trout streams so careful selection of species and life stages will be an important part of our initial analysis. Second, the list encompasses large, recreationally important, frequently migratory species like northern pike, as well as small, nongame species listed as 'species at risk'. The nongame species may be of high priority as well, for example, pearl dace and sauger, but for which very little fish passage information is available.

Project Personnel

The bulk of this project will be carried out by the principal investigators, two graduate students (one in Civil Engineering and one in Fish & Wildlife Science), and temporary undergraduate assistants. A post doctoral researcher will be recruited in the later half of the project to assist with project management and oversight.

Initial Field Observations

The stream flow rates that exist during critical fish passage periods will be predicted at each crossing in the study basins. If the basins are not gauged, critical flows will be estimated by correlating to similar nearby gauged basins, or by using accepted hydrologic runoff estimates and return-interval based storms. In addition, stream flow measurements will be used to ground-truth the hydrologic predictions. Because these flow rates will be used to assess fish passage limitations, the dimensions and hydraulic characteristics of each crossing will also be measured. Measurements will include:

- culvert length, slope, shape and cross-sectional dimensions,
- culvert type, material, hydraulic roughness, and inlet and outlet characteristics
- upstream and downstream channel descriptions,
- evidence of backwater, perched outlets or other hydraulic abnormalities.

To assess contextual factors that may affect 'success' or 'failure' of a culvert to provide adequate fish passage, we will also determine the stream channel type, surrounding soil type, and age (date

of construction) of a culvert. Upstream and downstream photo points at each culvert will also be established. Anecdotal observations, such as high water marks, debris, physical damage and physical wear will also be noted at teach culvert. At sites that have as-built drawings available, it will be interesting to note the changes at the site that have occurred since installation.

Passage Prediction

All of the culverts in the study will be modeled using FishXing.

Direct Measurements of Fish Passage

Direct assessment of fish passage at all culverts will be used to identify the success of fish passage in terms of timing and fish size class. Mark-recapture techniques will be combined with the use of PIT (passive integrated transponder) tags and tracking equipment. PIT tags can be used to track the movement of previously cataloged individual fish. A population sample is collected and tags are inserted into cataloged fish. The fish are released at a point, and the antennae shown in Figure 2 logs the passage of fish through a stream cross section. The significant value of use of this technology is to monitor fish passage directly over a wide variety of flow conditions.

Figure 2. A PIT tag antenna installed near a culvert (Biomark, Inc.)

Species Continuity Determination

Fish populations will be sampled by single pass electrofishing a 100 m (328 ft) section of stream above and below each culvert. Differences in length-frequency distribution will be developed to

statistically test for differences in population density of size distribution above and below the culvert.

Statistical Analyses

Statistical modeling will be used to correlate the passibility of the culvert with the species differentiation above and below the culvert. Our aim is to develop a probabilistic modeling tool that will predict degree of passage of culverts with different hydraulic characteristics at different flows.

**Products**

Tangible products that will be developed in this project include, but are not limited to:

- quarterly reports, the draft final report, and the final report,
- photographs of all research sites,
- the complete and annotated data set from field observations and model runs,
- one Master of Science thesis in Civil Engineering,
- one Master of Science thesis in Fish & Wildlife Science,
- publications for use by MDT and other interested agencies, and
- refereed publications for the academic community.

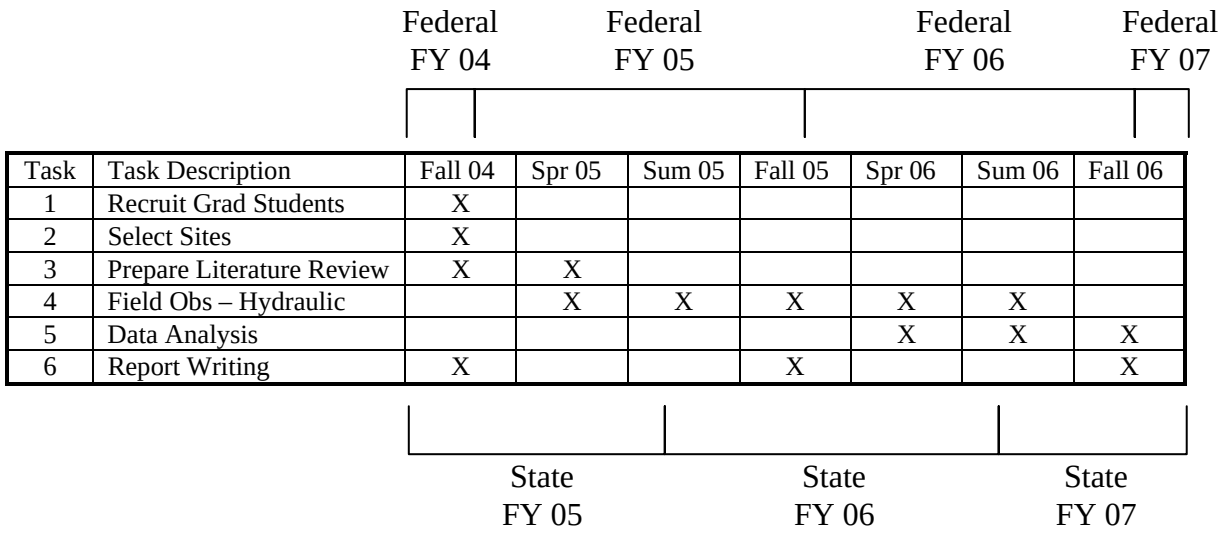
Our overall approach follows the model that we believe worked well in our previous work. That is, having graduate students in civil engineering and fisheries work jointly to collect and analyze the data. We have found this model to work very well in maximizing the quality of information collected, providing products useful and understandable to both professional groups, and encouraging training of individuals in both professions that have an understanding and appreciation for how each discipline views the world.

**Implementation**

The MDT, MFWP and USFS will be direct recipients of most of the products listed above. These agencies may want to use this information to formulate broad reaching policies concerning fish passage. This work should improve our understanding of the hydraulic and biologic features that must be evaluated to design road crossings.

**Time Schedule**

The time schedule for the project is shown below. With heavy student participation it is convenient to think of the project in terms of semesters. The first semester (Fall 2004) will be devoted to selecting sites for the field surveys, collection of hydrologic data, and recruiting graduate students. The bulk of the project - field activities, data collection, data analysis, report writing, etc. – will take place during the 2005 and 2006 calendar years. This arrangement places the summers, when most of the field activity will take place, in the middle of the project rather than at the beginning or end. This schedule also provides coincidence of field activity with fish spawning and migration time periods.




| Task | Task Description | Fall 04 | Spr 05 | Sum 05 | Fall 05 | Spr 06 | Sum 06 | Fall 06 |
|---|---|---|---|---|---|---|---|---|
| 1 | Recruit Grad Students | X | | | | | | |
| 2 | Select Sites | X | | | | | | |
| 3 | Prepare Literature Review | X | X | | | | | |
| 4 | Field Obs – Hydraulic | | X | X | X | X | X | |
| 5 | Data Analysis | | | | | X | X | X |
| 6 | Report Writing | X | | | X | | | X |

**Staffing**

| Name/Classification | Role | Hours Contributed to Task | | | | | | Total |
|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | |
| Cahoon | Principal Investigator | 15 | 25 | 10 | 60 | 30 | 30 | 170 |
| McMahon | Co-Principal Investigator | 5 | 25 | 10 | 60 | 55 | 15 | 170 |
| Stein | Co-Principal Investigator | 5 | 5 | 5 | 15 | 10 | 10 | 50 |
| Barber | Co-Principal Investigator | 0 | 50 | 0 | 0 | 25 | 10 | 85 |
| Post-Doctoral | Project Management | 0 | 0 | 0 | 300 | 300 | 300 | 900 |
| Grad Student 1 | Graduate Assistant | 0 | 0 | 460 | 940 | 800 | 200 | 2400 |
| Grad Student 2 | Graduate Assistant | 0 | 0 | 460 | 940 | 800 | 200 | 2400 |
| Undergraduate Student | Student Intern | 0 | 0 | 0 | 76 | 76 | 10 | 162 |
| Budget Admin/Support | Accounting and Clerical | 6 | 0 | 0 | 6 | 0 | 6 | 18 |

**Facilities**

Montana State University has all the equipment and facilities necessary to complete this project except for PIT tags, the PIT tag reader/logger, the electrofisher, and associated computer equipment. MSU equipment includes surveying and measurement equipment, desktop computers and software.

**MDT Involvement**

Project personnel will work with MDT personnel (Sue Sillick) to coordinate reporting, documentation and the release of data and project information. Other MDT personnel will be consulted on an as-needed basis concerning site selection and access to historic records or documents.

## Budget

| Category | Federal Fiscal Year Budget (October 1 to September 30) FY04 | FY05 | FY06 | FY07 | Category Total | State Fiscal Year Budget (July 1 to June 30) FY05 | FY06 | FY07 | Category Total |
|---|---|---|---|---|---|---|---|---|---|
| **Salaries** | | | | | | | | | |
| Cahoon | 0 | 1500 | 1500 | 0 | 3000 | 0 | 1500 | 1500 | 3000 |
| Barber | 0 | 1500 | 1500 | 0 | 3000 | 0 | 1500 | 1500 | 3000 |
| McMahon | 0 | 3000 | 3000 | 0 | 6000 | 3000 | 0 | 3000 | 6000 |
| Post Doc | 0 | 4000 | 12000 | 3000 | 19000 | 1000 | 12000 | 6000 | 19000 |
| RA Engr | 0 | 9000 | 12000 | 3000 | 24000 | 6000 | 12000 | 6000 | 24000 |
| RA FWS | 0 | 9000 | 12000 | 3000 | 24000 | 6000 | 12000 | 6000 | 24000 |
| Undergraduate | 0 | 500 | 500 | 400 | 1400 | 400 | 600 | 400 | 1400 |
| **Fringe Benefits** | | | | | | | | | |
| Cahoon | 0 | 375 | 375 | 0 | 750 | 0 | 375 | 375 | 750 |
| Barber | 0 | 375 | 375 | 0 | 750 | 0 | 375 | 375 | 750 |
| McMahon | 0 | 750 | 750 | 0 | 1500 | 750 | 0 | 750 | 1500 |
| Post Doc | 0 | 1000 | 3000 | 750 | 4750 | 250 | 3000 | 1500 | 4750 |
| RA Engr | 0 | 420 | 480 | 60 | 960 | 240 | 480 | 240 | 960 |
| RA FWS | 0 | 420 | 480 | 60 | 960 | 240 | 480 | 240 | 960 |
| **In-State Travel** | 400 | 6000 | 6000 | 1500 | 13900 | 3400 | 6000 | 4500 | 13900 |
| **Out-of-State Travel** | 0 | 0 | 0 | 1000 | 1000 | 0 | 0 | 1000 | 1000 |
| **Supplies** | 0 | 2000 | 2000 | 0 | 4000 | 2000 | 1000 | 1000 | 4000 |
| **Publications** | 0 | 0 | 0 | 1000 | 1000 | 0 | 0 | 1000 | 1000 |
| **Equipment** | 35000 | 0 | 0 | 0 | 35000 | 35000 | 0 | 0 | 35000 |
| **Tuition and Fees** | 0 | 10600 | 10600 | 0 | 21200 | 5600 | 10600 | 5000 | 21200 |
| **Total Direct Costs** | 35400 | 50440 | 66560 | 13770 | 166170 | 63880 | 61910 | 40380 | 166170 |
| **Indirect Costs** | 60 | 7566 | 9984 | 2066 | 19675 | 4332 | 9287 | 6057 | 19676 |
| **Grand Totals** | 35460 | 58006 | 76544 | 15836 | 185845 | 68212 | 71197 | 46437 | 185846 |

**Budget Detail**

Salary - Dr.'s Cahoon, McMahon and Barber are on academic-year (9-month) contracts at MSU. The budget request includes a total of approximately 2 months salary for these three people. These are approximations, as their respective salaries are not equal. The university accounting system allows for this to be paid as summer-salary even though the hourly contributions to the project are spread over the project duration. No request is made for salary for Dr. Stein - his contribution will be covered in-house. Graduate students are paid a monthly stipend of $1000 and undergraduate employees pay varies from $7/hr to $10/hr based on qualifications. The post doctoral research will be employed part-time on this project at a rate of $21.11/hr.

Fringe Benefits - Faculty and post-doctoral fringe benefits are calculated at 25% of salary, graduate students fringe benefits are calculated at 2% when enrolled full-time in classes, and 10% when not enrolled (summer). Undergraduates are not assessed fringe benefits.

In-State Travel - Many miles will be logged visiting field sites to record research data.

Out-of-State Travel - Funds are requested to sent one project representative to a national conference or society meeting to present the results of the project.

Supplies - This project includes a considerable amount of field data collection and evaluation. As such, the request for supplies includes expendables, all less-than-$1000 purchases, and the maintenance needs associated with flow measurements, fish counts, computational tools, etc. If any single item exceeds the $1000 limit, a request will be made to adjust the budget so that that item becomes 'equipment' and is then property of MDT. Such purchases are not anticipated but will be accommodated if necessary.

Publications - It is anticipated that several media will host the results of the project - Internet based deliveries, printed brochures or design guides, professional society presentations and refereed journal articles. All of these have some combination of production, printing, or page-fee costs.

Equipment - The company that sells the PIT tagging equipment is Biomark, Inc. Five culverts will be equipped with the PIT readers at any given time. The breakdown is:

5 each tagging kits (TK-FS2001-ISO) at $3,800 each
5 each antenna cable extensions (ASCS-FS2-4MC) at $70 each
5 each DC power cables (ASCS-FS2-DC) at $95 each
5 each 12" x 36" antennas (ANT-FS2-12x31.5-001) at $1200 each
1 each data reader with cables and accessories (RD-PREX) at $495 each

This totals up to $26,320. The balance of the equipment request is for a backpack electrofisher.

Tuition and Fees - *Tuition and Fees* is the term that MSU uses to describe the total amount of money that a student pays directly to the University to attend, including tuition, lab fees, and user fees. *Tuition and Fees* does not include room, board, insurance or other incidental costs. There

is no automatic waiver of these costs for graduate research associates - the costs are either paid directly by the student or are reduced by actual monetary contributions from grants (such as this one), scholarships, or fellowships. The budget request includes *Tuition and Fees* for two students, each enrolled full-time for a total of four semesters. The request is approximately the average of the in-state and out-of-state rates. This allows us to recruit the best students possible, while giving the in-state students the monetary incentive of fully covered *Tuition and Fees*. Experience has shown that even when offering out-of-state students approximately 80% of their out-of-pocket *Tuition and Fees*, we still tend to recruit a desirable mix of in-state and out-of-state students.

**References**

Kane, D.L., and P.M. Wellen (1985). A Hydraulic Evaluation of Fish Passage Through Roadway Culverts in Alaska. Report: FHWA-AK-RD-85-24 and 85-24A. U.S. Department of Transportation.

Katopodis, C. and R. Gervais (1991). Ichthyomechanics. Winnipeg, Department of Fisheries and Oceans: 1-11.

Six Rivers National Forest Watershed Interaction Team. 1999. FishXing software, version 2.2.

Tillinger, T.N. and O.R. Stein. 1996. Fish Passage Through Culverts in Montana: A Preliminary Investigation. Federal Highway Administration FHWA/MT/96/8117-2.

**Dr. Joel Eugene Cahoon, Ph.D., P.E.**
Civil Engineering Department, 220 Cobleigh Hall
Montana State University, Bozeman, MT 59717
(406) 994-5961 joelc@ce.montana.edu

**Education**

| | | | |
|---|---|---|---|
| B.Sc. | Agricultural Engineering | New Mexico State University | 1985 |
| M.Sc. | Agricultural Engineering | Montana State University | 1987 |
| Ph.D. | Engineering | University of Arkansas | 1989 |

**Employment**

ASSISTANT and ASSOCIATE PROFESSOR. Civil Engineering Department, Montana State University, Bozeman, Montana. January 1995 - present. Teach undergraduate water resources engineering courses in the Civil Engineering Department and conduct research in water resources engineering as related to agricultural and rural issues for the Montana Agricultural Experiment Station and the Engineering Experiment Station.

INTERIM DEPARTMENT HEAD. Civil Engineering Department, Montana State University, Bozeman, Montana. September 2001 – June 2002. Supervise all departmental functions including academic issues, fiscal policy, research and outreach for a department with 26 faculty and 650 students.

ASSISTANT PROFESSOR. Biological Systems Engineering Department, University of Nebraska, Lincoln, Nebraska. March 1990 - December 1994. Research and cooperative extension related to water quality and applied water management.

**Societies and Registration**

Member, American Society of Civil Engineers
Registered Professional Engineer (PE) - Montana (12322)

**Selected Publications**

Sanford, P., J.E. Cahoon and T. Hughes. 1998. Modeling a concrete block irrigation diversion system. *Journal of the American Water Resources Association.* 34(5):1179-1187.

Cahoon, J., D. Baker and J. Carson. 2002. Factors for rating the condition of culverts for repair or replacement needs. *Transportation Research Record* No. 1814, Design of Structures. 197-202.

Cahoon, J. and T. Hoshino. 2003. A flume for teaching spatially varied open-channel flow. *Journal of Hydraulic Engineering.* ASCE. 129(10)813-816.

Towler, B. W., J. E. Cahoon, O. R. Stein. 2004. Evapotranspiration coefficients for cattail and bulrush. *ASCE J. Hydrologic Engineering.* 9(3):235-239.

Klara, M., J. E. Cahoon and O. R. Stein. 2004. Generalized description of natural stream channel geometry. Submitted to *Journal of Hydraulic Engineering.* ASCE. May 2004.

**Thomas E. McMahon**
Professor of Fisheries, Ecology Department, Fish and Wildlife Program
Montana State University
406/994-2492; tmcmahon@montana.edu
www.montana.edu/~wwwbi/staff/mcmahon/mcmahon-msu-ecol.html

**Education**

- Ph.D. Fisheries Science, University of Arizona, 1984
- M.S. Fisheries Science, University of Arizona, 1978
- B.A. Aquatic Biology, University of California-Santa Barbara, 1975

**Academic and Visiting Appointments**

- Assistant/Associate/Full Professor of Fisheries, Ecology Department, Fish and Wildlife Program, Montana State University-Bozeman, 1990-present.
- Assistant Professor, Oregon State University, Marine Science Center, Newport, 1987-1990.
- Visiting Scientist, Pacific Biological Station, Canada Dept. of Fisheries and Oceans, Nanaimo, British Columbia, 1984-87.

**Honors and Awards**

- Governor-appointed member of Future Fisheries Habitat Review Panel, Montana Fish, Wildlife, and Parks, 2003- present.
- Elected Western Division Representative, Education Section, American Fisheries Society, 2003-2005.
- President, Montana Chapter, American Fisheries Society, 1998-99 (150 members).
- Associate Editor, North American Journal of Fisheries Management, 1996-98
- Most Significant Paper Award, North American Journal of Fisheries Management, 1996; Runner up, Journal of Aquatic Animal Health, 2003.
- Award for Outstanding Achievement in the Management of Natural Resources, Western Conservation Administrative Officers Association, 1993.
- Coordinator, Coastal Oregon Productivity Enhancement Program, College of Forestry, project leader for cooperative fishery, forestry, and wildlife program, budget of $500K, 1987-90.

**Selected Publications**

- Munro, A.R., T.E. McMahon, and J.R. Ruzycki. Natural chemical markers identify source and date of introduction of an exotic species: lake trout (*Salvelinus namaycush*) in Yellowstone Lake. Canadian Journal of Fisheries and Aquatic Sciences, in press.
- Hartman, G.F., and T.E. McMahon. 2004. Aspects of fish reproduction and some implications of forestry activities. Pages 143 to 168 IN T.G. Northcote and G.F. Hartman (eds.). Fishes and Forestry- Worldwide Watershed Interactions and Management. Blackwell Science.
- Rich, C.F. Jr., T.E. McMahon, B.E. Rieman, and W.L. Thompson. 2003. Local habitat, watershed, and biotic features associated with bull trout occurrence in Montana streams. Transactions of the American Fisheries Society 132:1053-1064.
- Munro, A.R., T.E. McMahon, S.A. Leathe, and G. Liknes. 2003. Evaluation of batch marking small rainbow trout with coded wire tags. North American Journal of Fisheries Management 23:601-605.
- Downing, D.C., T.E. McMahon, B.L. Kerans, and E.R. Vincent. 2002. Relation of spawning and rearing life history of rainbow trout and susceptibility to *Myxobolus cerebralis* infection in the Madison River, Montana. Journal of Aquatic Animal Health 14:191-203.
- Nelson, M.L., T.E. McMahon, and R.F. Thurow. 2002. Decline of the migratory form in bull charr, *Salvelinus confluentus*, and implications for conservation. Environmental Biology of Fishes 64:321-332.
- Selong, J.H., T.E. McMahon, A.V.Zale, and F.T. Barrows. 2001. Effect of temperature on growth and survival of bull trout, with application of an improved method for determining thermal tolerance in fishes. Transactions of the American Fisheries Society 130:1026-1037.

- McMahon, T.E., and W.M. Gardner. 2001. Status of sauger in Montana. Intermountain Journal of Sciences 7:1-21.
- Jakober, M.J., T.E. McMahon, and R.F. Thurow. 2000. Diel habitat partitioning by bull charr and cutthroat trout during fall and winter in Rocky Mountain streams. Environ. Biology of Fishes 59:79-89.
- Jakober, M.J., T.E. McMahon, and R.F. Thurow. 1998. Role of stream ice on fall and winter movements and habitat use by bull trout and cutthroat trout in Montana headwater streams. Transactions of the American Fisheries Society 127:223-235.
- McMahon, T.E., A.V. Zale, and D.J. Orth. 1996. Aquatic Habitat Measurements. Pages 83-120 IN B. Murphy and D. Willis, (eds.). Fisheries Techniques, 2nd edition. American Fisheries Society.
- Dalbey, S.R., T.E. McMahon, and W. Fredenberg. 1996. Effects of electrofishing pulse shape and electrofishing-induced spinal injury on long-term growth and survival of wild rainbow trout. North American Journal of Fisheries Management 16:560-569. (Received best paper award for 1996)
- Magee, J.P., T.E. McMahon, and R.F. Thurow. 1996. Spatial variation in spawning habitat and redd characteristics of cutthroat trout inhabiting a sediment-rich stream basin. Transactions of the American Fisheries Society 125:768-779.
- McMahon, T.E., S.R. Dalbey, S.C. Ireland, et al. 1996. Field evaluation of visible implant tag retention by brook trout, cutthroat trout, rainbow trout, and Arctic grayling. North American Journal of Fisheries Management 16:921-925.

**Courses Taught**

Introduction to Fish and Wildlife
Principles of Fish and Wildlife Management
Research Methods and the Scientific Process
Topics in Fish Ecology
Fisheries Management

**Otto R. Stein Jr.**

Associate Professor, Civil Engineering Department
Montana State University, Bozeman, MT 59717
406-994-6121 Fax: 406-994-6105 E-mail: ottos@ce.montana.edu

**Education**

| | |
|---|---|
| Doctor of Philosophy, 1990 | Colorado State University, Department of Civil Engineering |
| Master of Science, 1983 | Purdue University, Department of Agronomy |
| Bachelor of Science, 1980 | Pennsylvania State University, Environ. Resource Management |

**Professional Experience**

Associate Professor, Civil Engineering Department, Montana State University, 1996-Present
Assistant Professor, Civil Engineering Department, Montana State University, 1990-1996

**Professional Affiliations**

American Society of Agricultural Engineers
American Society of Civil Engineers
International Association for Hydraulic Research
International Water Association

**Honors and Awards**

Gamma Sigma Delta Honor Society
College of Engineering Outstanding Instructor Award, 1991
Bio-Resources Engineering Professor of the Year, 1992, 1993, 1995

**Selected Publications**

- Riley, K.A., O.R. Stein and P.B. Hook. 2003. Ammonium Removal in Constructed Wetland Microcosms as Influenced by Presence and Species of Plants and Organic Carbon Load. Water Research Submitted.

- Stein, O.R., P.B. Hook, J.A. Biederman, W.C. Allen and D.J. Borden. 2003. Does Batch Operation Enhance Oxidation in Subsurface Constructed Wetlands? Water Sci. and Tech. In Press.

- Stein, O.R. and D.A. LaTray. 2002. Experiments and Modeling of Headcut Migration in Stratified Soils. Water Resources Research. 38(12):1284:doi:10.1029/2001WR001166.

- Alonso, C.V., S.J. Bennett and O.R. Stein. 2002. Predicting Headcut Erosion and Migration in Concentrated Flows Typical of Upland Areas. Water Resources Research. 38(12):1303:doi:10.1029/2001WR001173.

- Stein, O.R., P.B. Hook, J.A. Biederman, W.C. Allen and D.J. Borden. 2002. Does Batch Operation Enhance Oxidation in Subsurface Constructed Wetlands? Oral Presentation Proc. 8th Inter. Conf. On Wetland Systems for Water Pollution Control. Sept. 16-19, 2002 Arusha, Tanzania. Pgs. 177-189.

- Borden, D.J., O.R. Stein and P.B. Hook. 2001. Seasonal Effects of Supplemental Organic Carbon on Sulfate Reduction and Zinc Sulfide Precipitation in Constructed Wetlands Microcosms. Proc. International Ecological Engineering Conference, pp. 296-300. Oral Presentation Nov. 26-29, 2001, Lincoln Univ., New Zealand.

**Jarrett Jay Barber**
Duke University Institute of Statistics & Decision Sciences
Room 219A Old Chemistry Building, Box 90251, Durham, NC 27708-0251
voice: (919) 684-8753 fax: 684-8594 email: jarrett@stat.duke.edu

## Education

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|---|---|---|
| Ph.D. Statistics | 2002 | North Carolina State University |
| M.S. Mathematics | 1997 | Northern Arizona University |
| M.S. Forestry | 1992 | Northern Arizona University |
| B.S. Forestry | 1990 | Northern Arizona University |

## Recent Employment

Visiting Assistant Professor. Spring 2002 - Present. Duke University Institute of Statistics and Decision Sciences, Durham, NC, jointly as Visiting Scientist, National Center for Atmospheric Research Geophysical Statistics Project, Boulder, CO.

NSF/VIGRE Graduate Student Fellow. Fall 99 - Spring 02. North Carolina State University Department of Statistics, Raleigh, NC.

Associate. Fall 99 - Fall 00. Environmental Careers Organization (ECO; USEPA Sponsor) RTP, NC.

## Recent Relevant Publications and Presentations

Barber, Jarrett J., and Alan E. Gelfand. 2003. Hierarchical spatial modeling for estimation of population size. Submitted to JABES.

Barber, Jarrett J., and Alan E. Gelfand. 2003. Spatial modeling of population size. Proceedings of the ISI International Conference on Environmental Statistics and Health, July 16 - 18, Santiago de Compostella, Spain.

Barber, Jarrett J. and Michael L. Lavine. State space models for ecological time series. Invited talk. Uncertainty and Information in Ecological Forecasting Symposium. Ecological Society of America Meetings, August 4-9, 2002, Tucson, AZ.

Statistics for Large Data Sets. Participant. National Center for Atmospheric Research (NCAR). July 2000, Boulder, CO.

## Fellowships, Honors, and Awards

NSF/VIGRE Fellowship, NCSU Statistics
Member - Mu Sigma Rho and Phi Kappa Phi
Outstanding M.S. Candidate, NCSU Statistics
ARCS Foundation Fellowship, NAU Forestry